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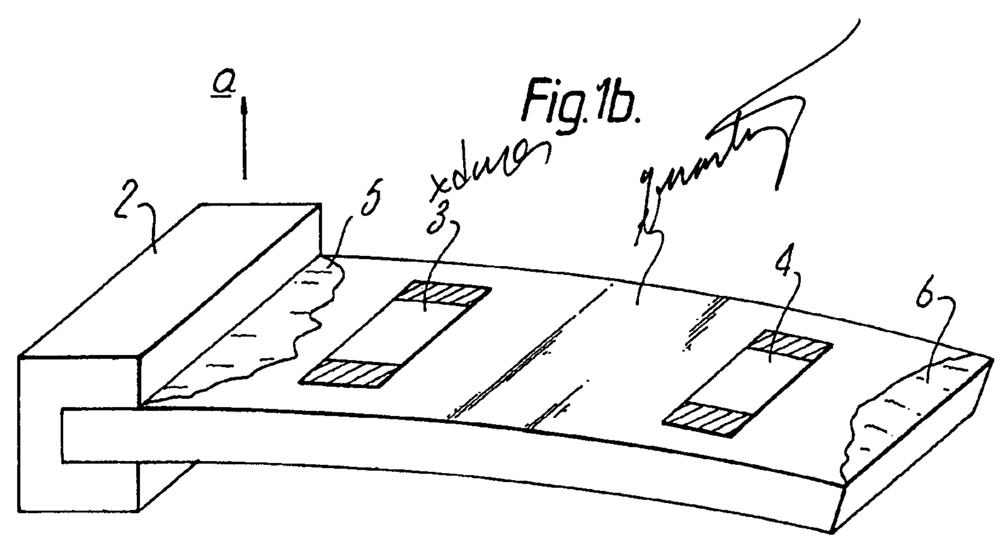
(54) **Surface acoustic wave accelerometer**

(57) An accelerometer comprises a resilient strip of quartz 1 on one face of which are formed surface acoustic wave transducers 3, 4 connected in the feedback loop of an amplifier to form an oscillator. The strip 1 is mounted in a support member 2 which is movable in a direction *a* normal to the plane of the strip whereby the resilient strip will bend because of inertial resistance to acceleration forces. This bending of the strip alters the amplifier loop delay and hence the oscillator frequency f. Arrangements are disclosed for compensating for temperature variations and unwanted coupling (Figs. 3 to 5). Alternatively, a reference frequency may be provided from a surface acoustic wave device mounted on a rigid strip (Fig. 6). A heater may be controllable to maintain the accelerometer at a constant temperature (Fig. 7).

Fig.1b.



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

Fig.1a.

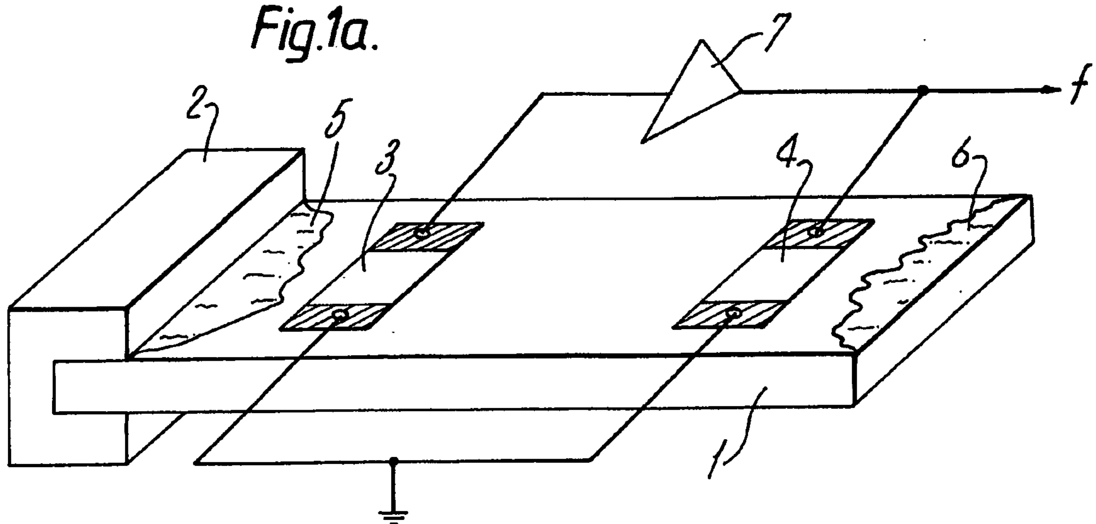


Fig.1b.

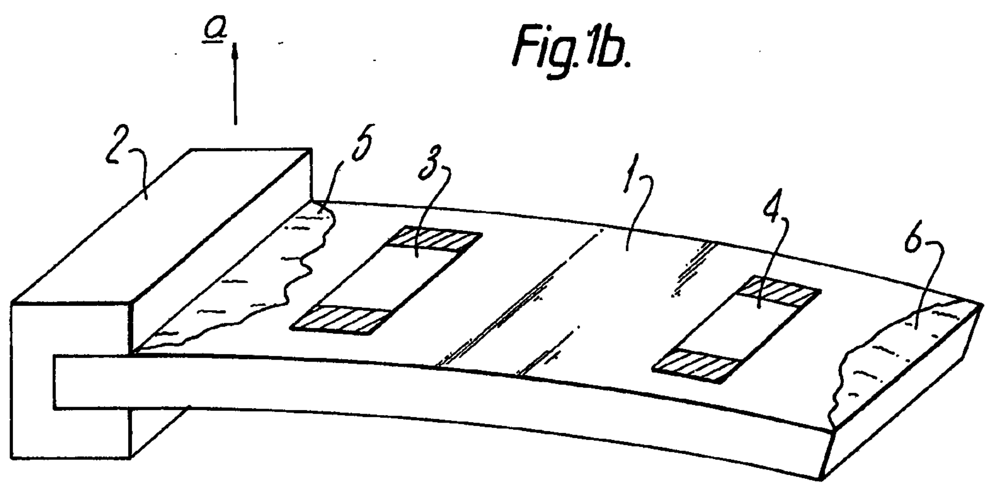


Fig.2a.

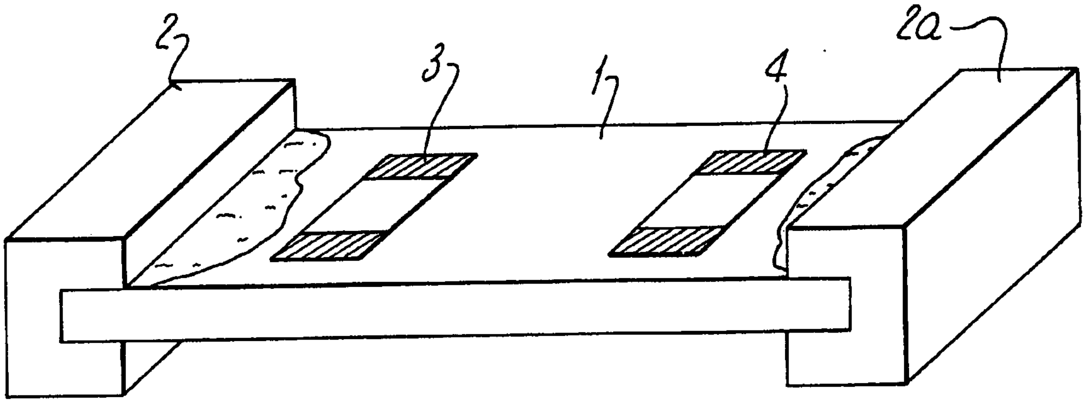


Fig.2b.

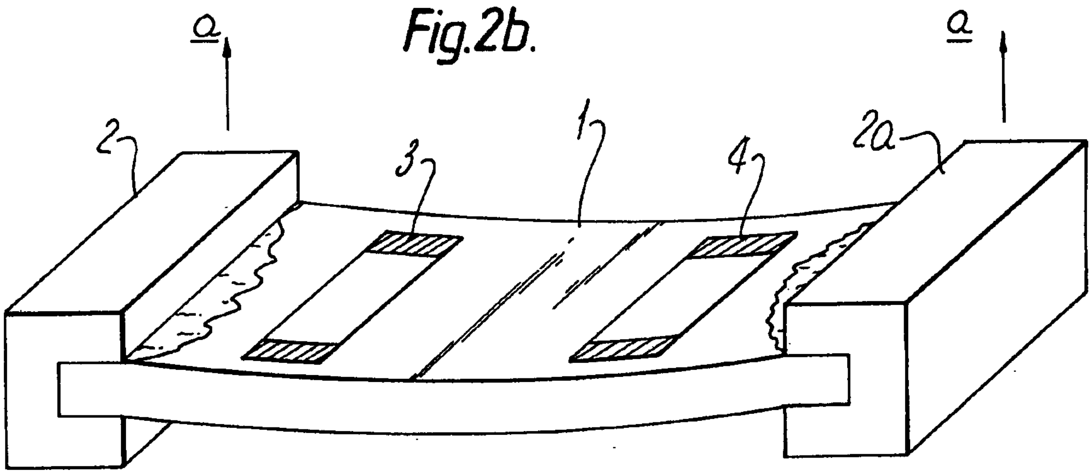


Fig.3.

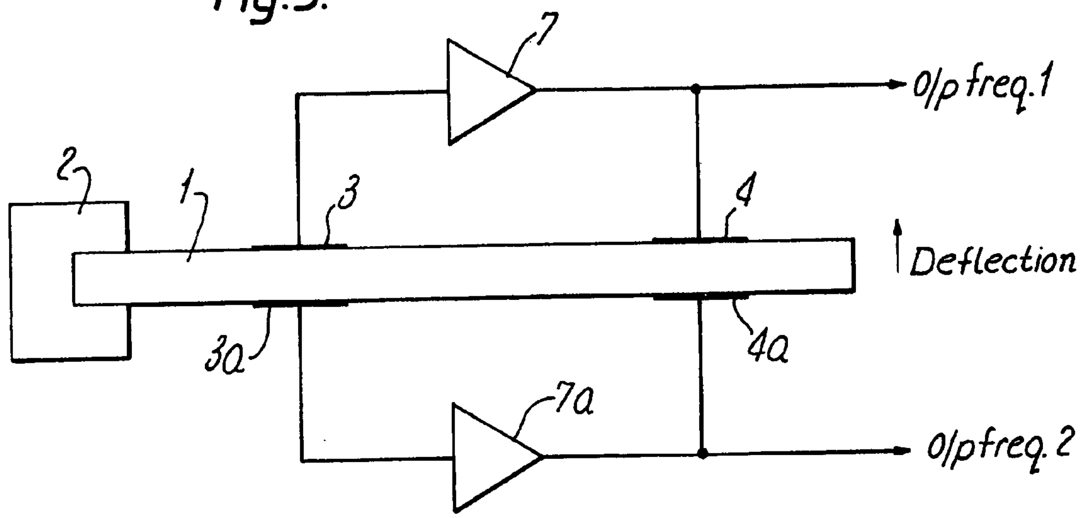

7
0/p freq.1
2
1
3
4
Deflection
3a
4a
7a
0/p freq.2

Fig.4.

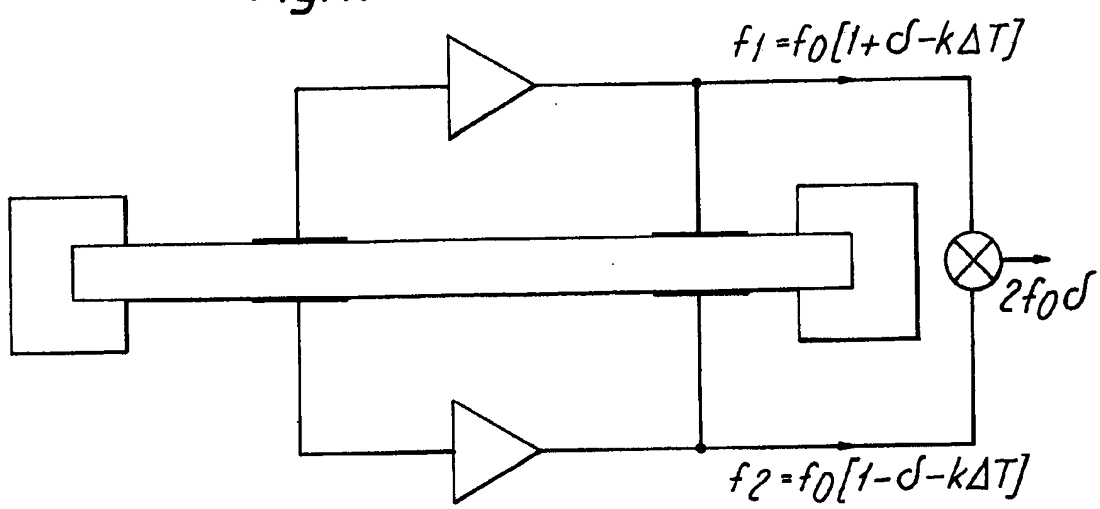

$f_1 = f_0[1+\delta-k\Delta T]$
$2f_0\delta$
$f_2 = f_0[1-\delta-k\Delta T]$

Fig.5.

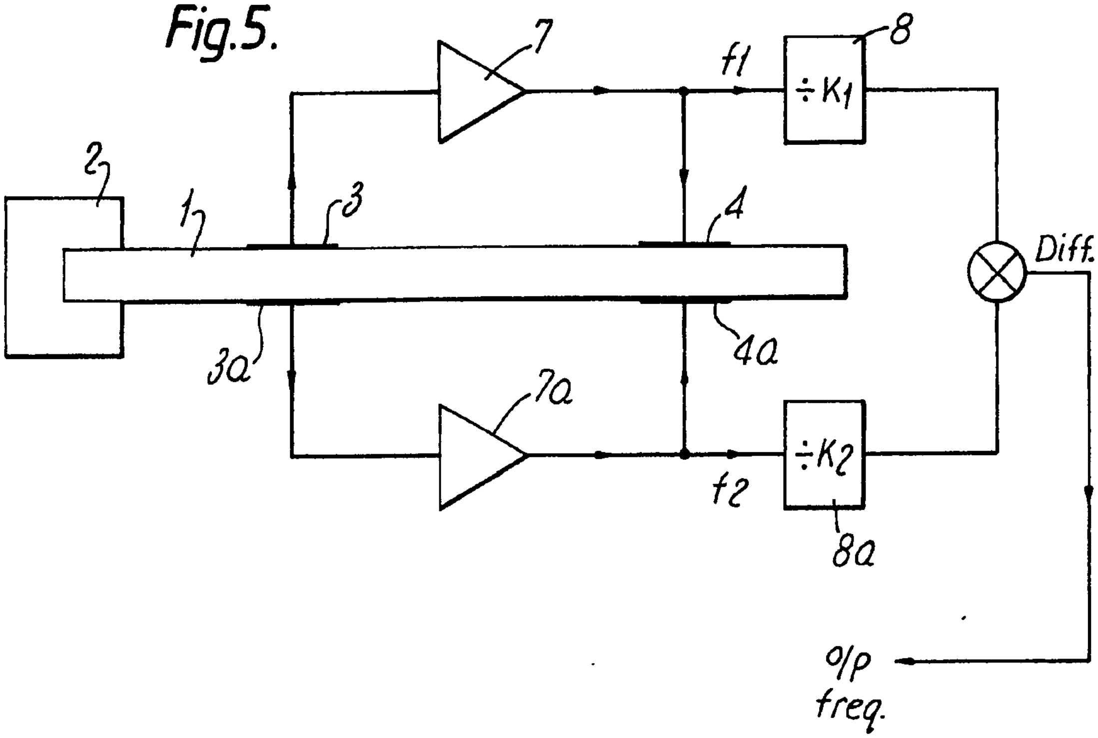
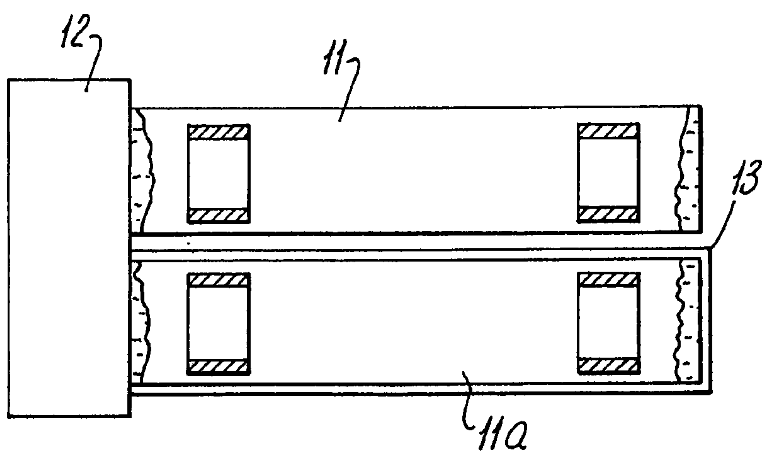


Fig.6.



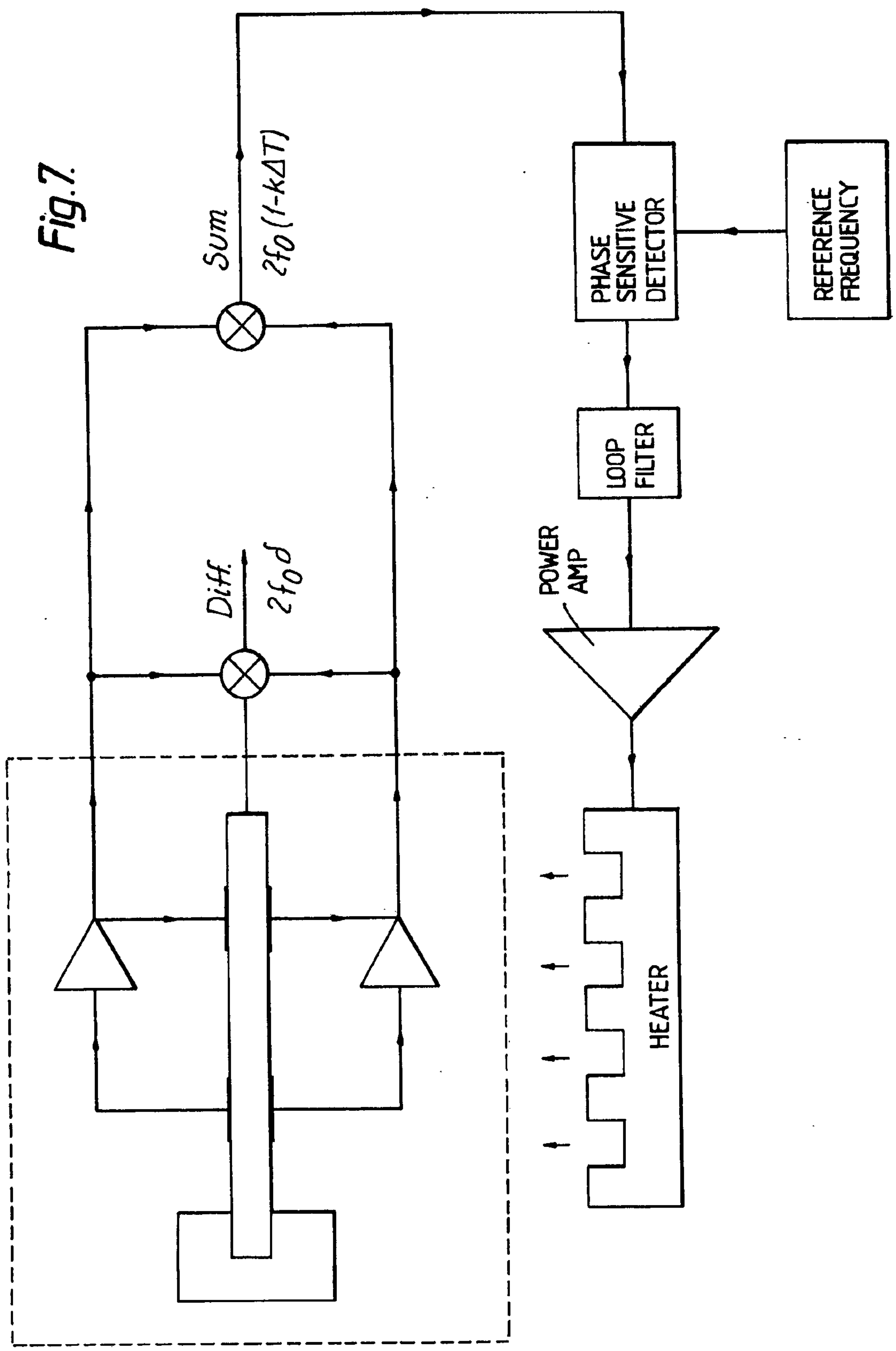

Sum
2f0(1-kΔT)
Diff.
2f0δ
PHASE SENSITIVE DETECTOR
REFERENCE FREQUENCY
LOOP FILTER
POWER AMP
HEATER

Fig.7.

SPECIFICATION

Surface acoustic wave accelerometer

This invention relates to a surface acoustic wave accelerometer device.

A typical simple accelerometer comprises a mass maintained in a neutral position in a system by means of springs. It remains in this neutral position so long as the system as a whole remains at rest or is in motion at a constant velocity. When the system is accelerated, i.e. is subjected to a change of velocity, the mass will, because of its inertia, lag behind the system movement. This movement of the mass relative to the rest of the system can be detected and used to control e.g. an electrical circuit to give a signal representative of the acceleration.

According to the present invention there is provided an accelerometer device comprising a resilient strip substrate of surface acoustic wave material provided with surface acoustic wave transducers arranged on a wave propagation path, at least one end of the strip being secured in a support member whereby acceleration of the support member in a direction normal to the plane of the strip will result in bending of the strip and a change in the propagation path whereby the acceleration can be measured by measuring the change in propagation path.

According to another aspect of the invention there is provided a method of measuring acceleration of a body wherein a resilient strip of surface acoustic wave material provided on at least one face with surface acoustic wave transducers arranged on a wave propagation path is subjected to bending in a direction normal to the plane of the strip in response to acceleration of the body resulting in a change in the propagation path delay and utilising the change to provide a signal which is a measure of the acceleration.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:—

Figs. 1a and 1b illustrate a simple cantilever or single clamped semi-beam surface acoustic wave accelerometer,

Figs. 2a and 2b illustrate a double clamped beam accelerometer,

Figs. 3 and 4 illustrate differential output versions of the accelerometers of Figs. 1 and 2,

Fig. 5 illustrates an arrangement for de-coupling a differential accelerometer,

Fig. 6 illustrates an arrangement for obtaining ageing and temperature compensation of a surface acoustic accelerometer, and

Fig. 7 illustrates a feedback arrangement for temperature compensation of an accelerometer.

In the arrangement shown in Fig. 1a a quartz strip 1 is clamped at one end in a support 2 so that the strip forms a cantilever or semi-beam structure. Electroacoustic transducers 3, 4 are provided on the surface of the strip 1 whereby surface acoustic waves can be propagated from transducer 3 in the surface region of the quartz strip to transducer 4. Surface acoustic wave absorption means 5, 6 are provided at each end of the strip. The transducers 3 and 4 are electrically connected in a feedback loop of an amplifier 7 to form an oscillator the frequency of which is dependent on the loop delay.

If the support 2 is moved in a direction normal to the plane of the strip 1, with an acceleration *a*, the strip 1 bends as shown in Fig. 1b. This bending causes the surface acoustic wave path length between transducers 3 and 4 to change, resulting in a change in the oscillator frequency f. Typically a quartz substrate 1 inch long and 500 μm thick will withstand accelerations up to 5000 g. With oscillator frequencies of hundreds of MHz sensitivities of the order of 0.4 ppm/g are attainable whilst a stability of 10^{-3} ppm can be attained in the neutral condition.

As an alternative to the cantilevered structure of Figs. 1a and 1b a double clamped beam can be used, as shown in Figs. 2a and 2b. The structure is generally similar to that Figs. 1a and 1b except that the strip 1 is clamped at both ends and both supports 2, 2a will move as one during acceleration. The resultant bending of the strip is symmetrical about its centre, as shown in Fig. 2b.

Fig. 3 shows a cantilever structure similar to that of Fig. 1a but with two surface acoustic wave paths, one on either face of the strip 1. Each of the paths extending respectively between transducers 3, 4 and 3a, 4a is connected in a separate oscillator loop 7, 7a. When acceleration occurs a differential output is obtained. This has advantages for the subsequent signal processing, as will be readily recognised by those skilled in the art. A similar arrangement for the double clamped beam structure is shown in Fig. 4. If

$$f_1=f_0[1+\delta-k\Delta T]$$

and

$$f_2=f_0[1-\delta-k\Delta T],$$

where f_0 is the common neutral frequency of both loops, δ is the proportional path length change due to acceleration and $k\Delta T$ is a temperature coefficient of path length change, then

$$f_1-f=2f_0$$

(independent of ΔT to first order).

Should there by any problem of unwanted coupling between the two frequencies then a modification as shown in Fig. 5 can be used. Oscillator loop 7, 3, 4 can have a frequency:

$$f_1=k_1f_r$$

and loop 7a, 3a, 4a a frequency

$$f_2=k_2f_r,$$

where k_1 and k_2 are positive unequal integers and f_r is a nominal reference frequency. The output frequencies are then fed to respective divider

networks 8, 8a whose division ratios are k_1 and k_2 respectively.

Thus, during acceleration

$$f_1=k_1.f_r(1+\delta)$$

$$f_2=k_2.f_r(1-\delta)$$

The differential output is then $2f_r.\delta$. In this case there will be a loss of sensitivity as f_r is less than f_o.

One method of compensating for errors due to temperature and ageing is to provide a reference frequency which although subject to the same errors is invariant during acceleration. This reference frequency can then be compared with the variable frequency to determine the amount of change due solely to acceleration. Fig. 6 shows an arrangement in which two substantially identical surface acoustic wave structures 11, 11a are mounted side by side in a common support 12. The surface acoustic wave structure 11 is free to respond to acceleration forces as described above, whilst structure 11a is constrained to be inflexible by being bonded to a rigid backing 13.

One method of compensating for errors due to temperature and ageing is to provide a reference frequency which although subject to the same errors is invariant during acceleration. This reference frequency can then be compared with the variable frequency to determine the amount of change due solely to acceleration. Fig. 6 shows an arrangement in which two substantially identical surface acoustic wave structures 11, 11a are mounted side by side in a common support 12. The surface acoustic wave structure 11 is free to respond to acceleration forces as described above, whilst structure 11a is constrained to be inflexible by being bonded to a rigid backing 13.

Whilst the ageing effects in a surface acoustic wave device can probably be ignored, e.g. typically less than 10 ppm/year, temperature sensitivity is a factor which must be considered. Fig. 7 shows an arrangement in which a positive temperature correction is applied. The differential structure of Fig. 3 or Fig. 5 is used to provide a sum output $2f_o(1-k\Delta T)$ which is applied to a phase sensitive detector 14 together with a stable reference frequency from source 15 to produce a temperature control signal 16. This control signal is passed through a loop filter 17 and fed to a power amplifier 18 the output of which is applied to a heater 19. Heater 19 is arranged to keep the surface acoustic wave structure at a constant temperature.

Although the above descriptions refer to a delay-line surface wave oscillator, a practical alternative could employ a surface-wave resonator as the controlling element of an oscillator.

Claims

1. An accelerometer device comprising a resilient strip substrate of surface acoustic wave material provided with surface acoustic wave transducers arranged on a wave propagation path, at least one end of the strip being secured in a support member whereby acceleration of the support member in a direction normal to the plane of the strip will result in bending of the strip and a change in the propagation path whereby the acceleration can be measured by measuring the change in propagation path.

2. A device according to claim 1 wherein both ends of the strip are secured in support members whereby common movement of both support members in a direction normal to the plane of the strip will result in bending of the strip between the two ends thereof.

3. A device according to claim 1 or 2 wherein the strip is provided on opposing faces with separate substantially identical surface acoustic wave transducer arrangements having the same surface acoustic wave frequencies.

4. A device according to claim 1 or 2 wherein the strip is provided on opposing faces with separate surface acoustic wave transducer arrangements having different surface acoustic wave frequencies.

5. A device according to any preceding claim including a second rigid strip substrate of surface acoustic wave material provided with a substantially identical surface acoustic wave transducer arrangement to a transducer arrangement on the resilient strip.

6. A surface acoustic wave accelerometer device according to any preceding claim including means for obtaining an electrical signal representative of differential changes in frequency of surface acoustic wave propagating simultaneously in propagation paths on opposing faces of the strip and temperature compensating means responsive to said electrical signal to maintain constant the temperature of the device.

7. A device according to any preceding claim wherein the or each transducer arrangement is connected electrically in the feedback loop of an amplifier to form an oscillator the frequency of which is dependent on the loop delay.

8. A surface acoustic wave accelerometer device substantially as described with reference to the accompanying drawings.

9. A method of measuring acceleration of a body wherein a resilient strip of surface acoustic wave material provided on at least one face with surface acoustic wave transducers arranged on a wave propagation path is subjected to bending in a direction normal to the plane of the strip in response to acceleration of the body resulting in a change in the propagation path delay and utilising

the change to provide a signal which is a measure of the acceleration.

10. A method of measuring acceleration substantially as hereibefore described with reference to the accompanying drawings.

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